



Extraction Design
NuMI Dir. Rev.
2 April, '02
S. Childress

NuMI Extraction Channel Design

Includes inputs from **A. Drozhdin, C. Jensen, D. Johnson,**
P. Lucas and A. Marchionni



MI-60 Extraction for NuMI

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Baseline design similar to MI-52 extraction to P1:

However, some much more severe constraints for NuMI:

- Typical operation for 1 Booster batch to P1, 5 batches to NuMI
(higher intensity, larger emittance)
- Rigorous limits on allowable beam loss through NuMI primary transport.

Evaluation of MI-52 extraction function; projections to NuMI operation.



MI-52 Extraction Observations

(measurements by A. Marchionni, D. Johnson)

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- Much greater beam loss seen in Lambertson area, than for other MI regions.
- Typically, highest residual activation in MI tunnel (over last year, frequently to 200 mr/hr)
- Significant variations in beam loss seen over time
 - « Increases with intensity much faster than linearly
 - « Decreases with increasing kicker HV. Operation ~ 20% higher than design.
 - « Considerable reduction in beam loss by machine tuning, for same beam positions.
- Very tight extraction channel aperture - even for current MI intensity & single batch operation.



Extraction Loss & Aperture Simulation

(modeled by A. Drozhdin)

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- STRUCT program
 - « inputs include magnet channel geometry, corrector magnet strengths, quadrupole displacements)
 - « project beam distributions, estimate beam loss and aperture clearance
- Model comparisons to beam data ongoing for MI-52
- Recent detailed model study for MI-60 NuMI extraction
 - « beam inputs used: 12π mm.mrad at 95% for injection, 25π and 40π for extraction, model beam tails to 4σ . (Gaussian to 3σ ; 1/r for 3 to 4σ)



Kicker and Lambertson Parameters

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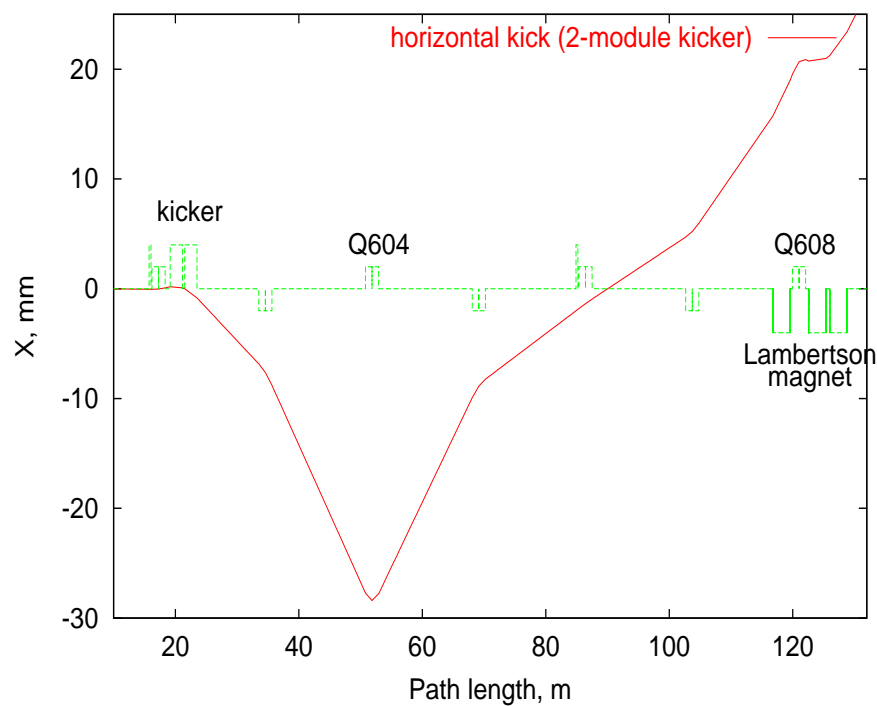
Kicker-magnets							
name	location	length	number	Max. kick	Max. field	field at 8 GeV	field at 120 GeV
		m		kG-m	kG	kG	kG
KM602A,B	MI-60	1.99	2	1.4625	0.734925		0.734925
K622A,B	MI-62	1.956	2				0.537182
K103A,B,C	MI-10	1.0922	3			0.093115	
K304	MI-30	1.956	1			0.166744	
K400	MI-40	1.89	2			0.079709	0.876225
K520	MI-52	1.9558	2			?	0.625831
Lambertson magnets							
name	location	length	number	Max. kick	Max. field	field at 8 GeV	field at 120 GeV
		m		kG-m	kG	kG	kG
LAM60A,B,C	MI-60	2.8	3	34.6	12.357		8.5774
LAM62A,B,C	MI-62	2.8	3	34.6	12.357		8.9
LAM10	MI-10	2.286	1			4.539610	
LAM222	MI-22	4.064	1		1.677	1.677	
LAM321	MI-32	4.064	1		1.677	1.677	
LAM40A,B,C	MI-40	2.8	3	34.6	12.357	0.555556	7.5
LAM52A,B,C	MI-52	2.8	3	34.6	12.357	?	9.3



MI-60 Extraction

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- Extracted beam central trajectory
- Baseline design

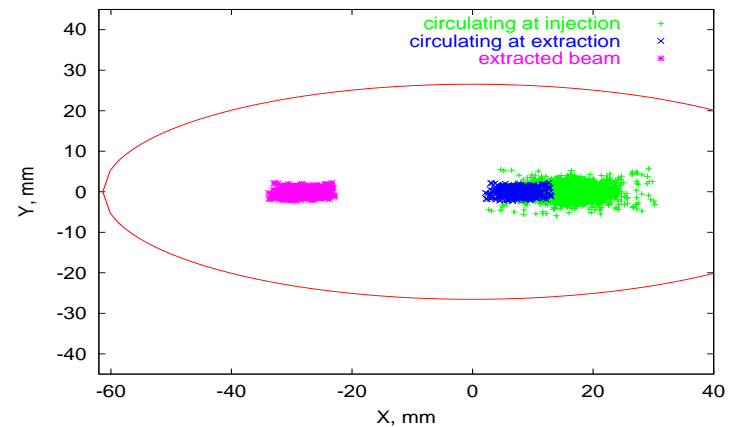




Beam profiles - Q604 and Q608 (between Lambertsons)

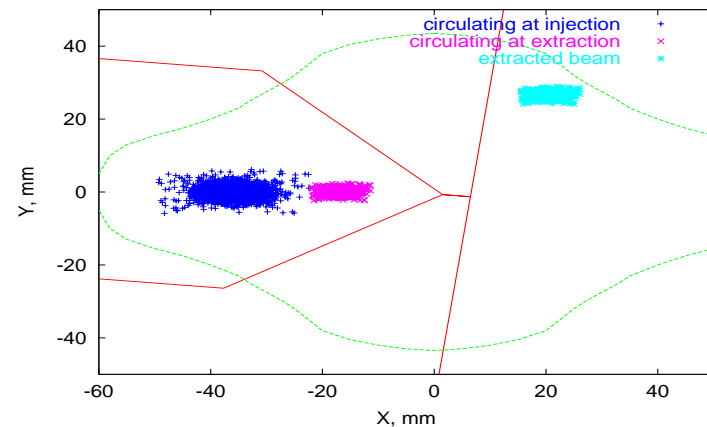
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- Circulating & extracted beam @ Q604



- Beams at Q608

Baseline 2-kicker design

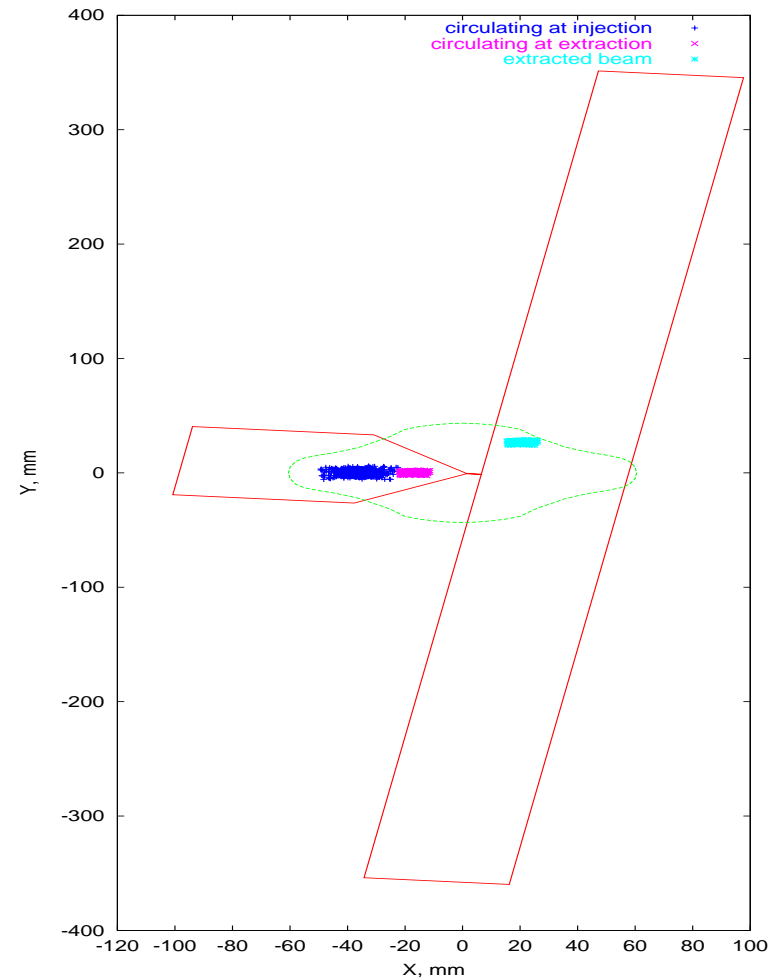




Expanded View - Extraction Channel Apertures

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- Impact of Lattice quad (Q608) between Lambertsons - 70% reduction in extraction channel aperture





Extraction Channel Aperture Clearance

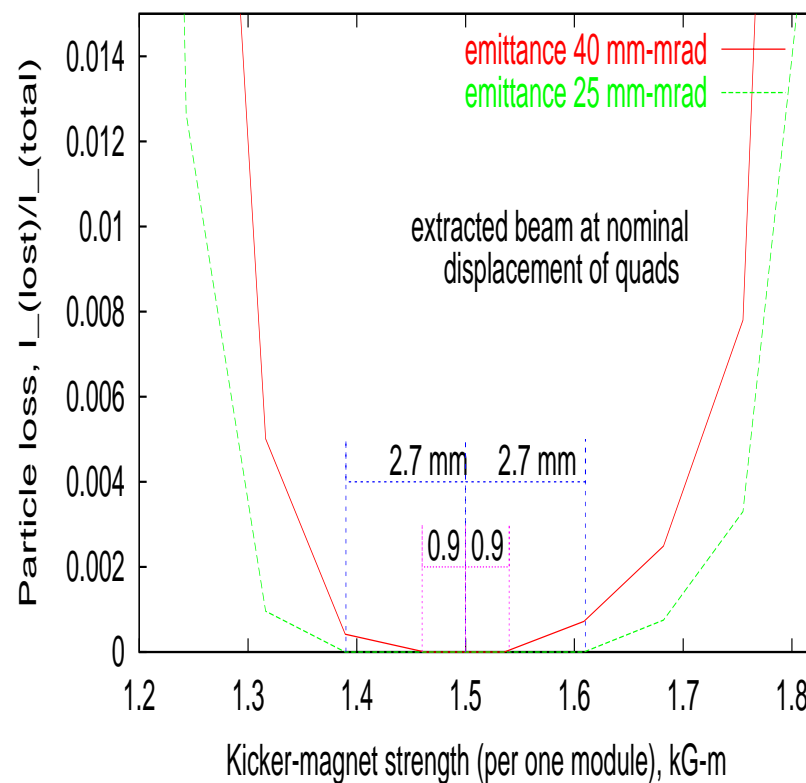
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- For baseline design -

25 π : < 3 mm clearance

40 π : < 1 mm clearance

Note also required kicker strength.





Kicker Constraints

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- Required kicker module strength of $\sim 1.45 - 1.5$ kG-m (1.99m length) is much greater than original design spec
 - « 1.12 kG-m (2250A) nominal and 1.38 kG-m(2650 A) maximum.
- C. Jensen indicates can reach higher strength by:
 - « additional ferrite in each module
 - « operation at 63 kV [maximum feasible, no tuning range]
 - « also concern for more kicker misfires at higher voltage.



Other Considerations

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- Baseline extraction channel is so severely restricted that in primary transport optics modeling, it is not considered - other-wise it dominates acceptance of NuMI line irrespective of transport optics details.
- Strong conclusion that a solution is needed here prior to high intensity NuMI operation.



Path Toward a Practical Solution

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- Open up effective extraction channel aperture
- Add enhanced kicker capability to utilize larger aperture.
- Attention to severe cost and schedule constraints.



Proposal for Solution

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- Add a second power supply to MI60 Lambertson string
 - « Decreased field in 1st Lambertson to keep beam away from Q608 aperture
 - « Increased field in magnets 2 and 3 to accomplish needed vertical kick
- Since can't increase kicker strength per module, add a 3rd kicker to provide more separation at Lambertsons.

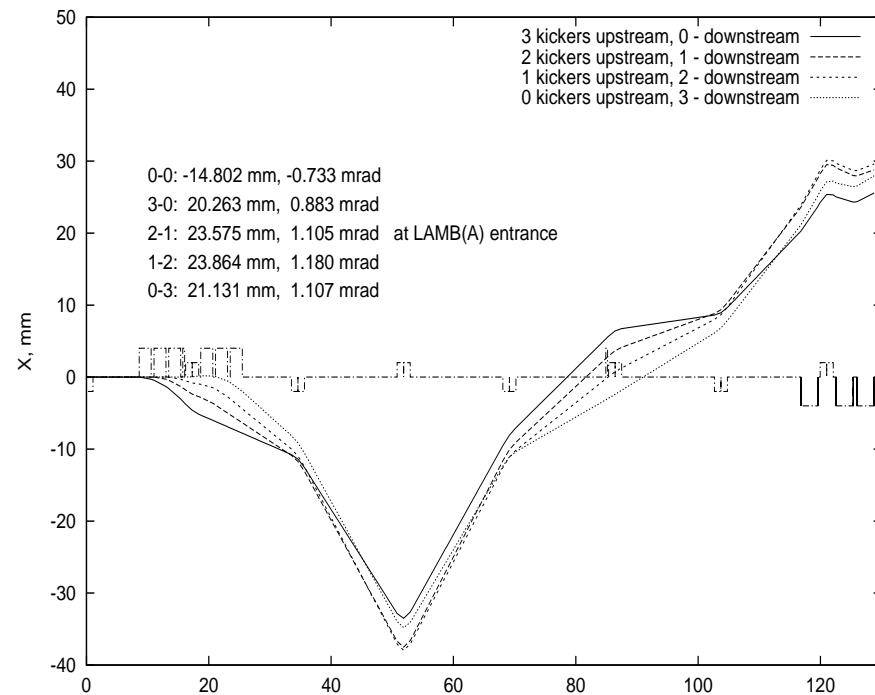
Detailed modeling of this solution by A. Drozhdin.



Locating 3 Kickers

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- Optimal placement is for new kicker upstream of Q602 (with corrector). # 2 & 3 remain downstream of Q602.
- All 3 kickers downstream of Q602 also provides good solution.

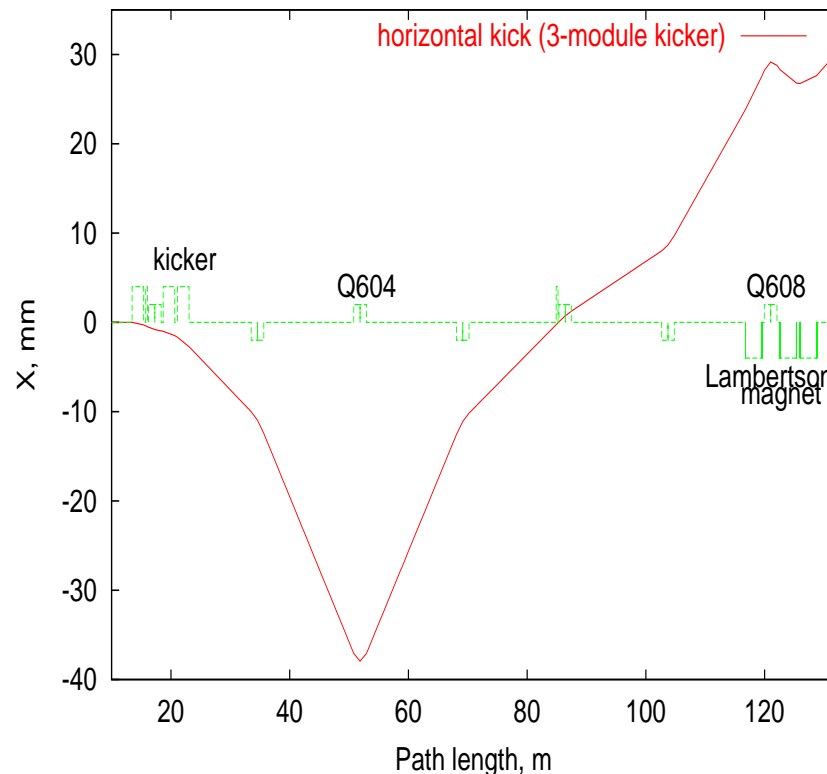




3 Kicker MI-60 Extraction

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- Extracted beam central trajectory
- Significantly enhanced beam separation at Lambertsons
- Must pay careful attention to beam excursion at Q604 also.

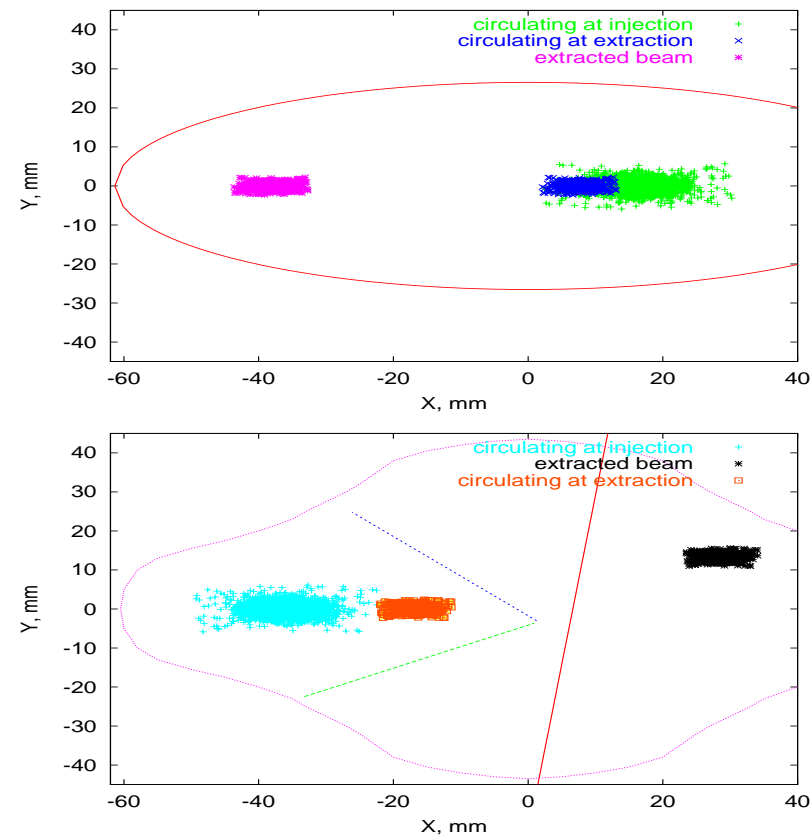




3 Kicker Beam profiles - Q604 and Q608

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- Circulating & extracted beam @ Q604
- Beams at Q608
- Effective aperture clearance now similar at Q604 and Q608





New Extraction Channel Aperture Clearance

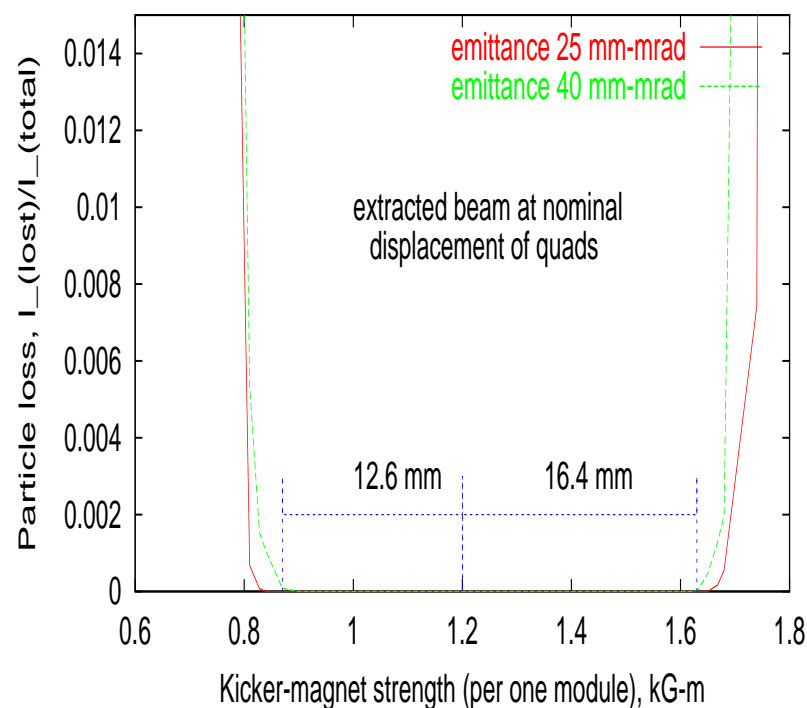
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- Three kicker, 2 Lam.PS design:

25 π : > x5 clearance gain

40 π : > x10 clearance gain

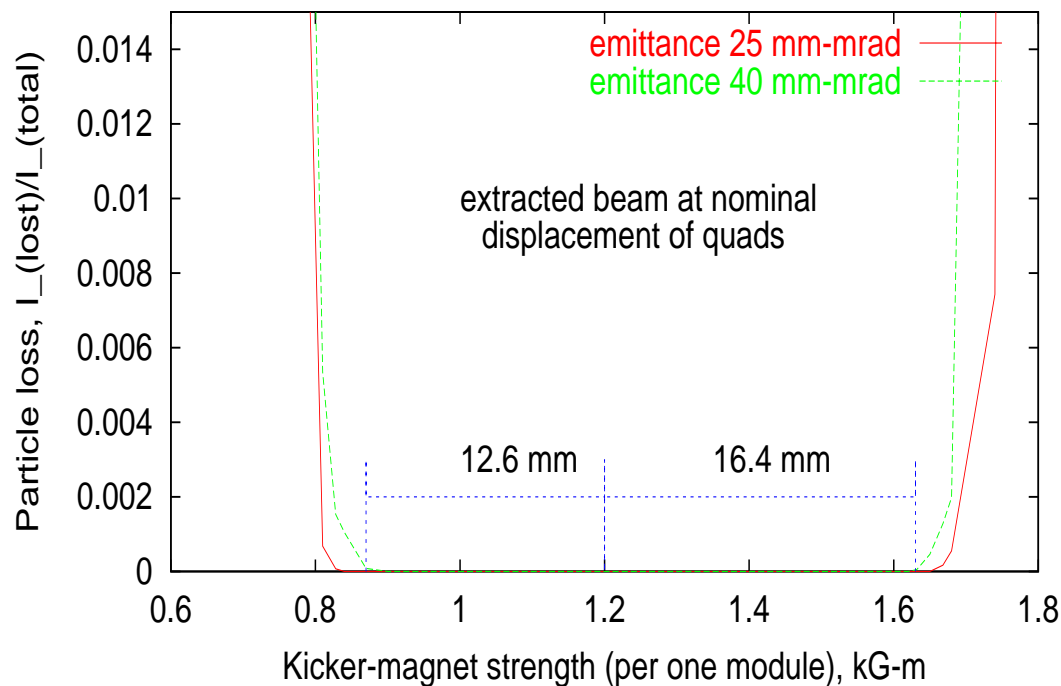
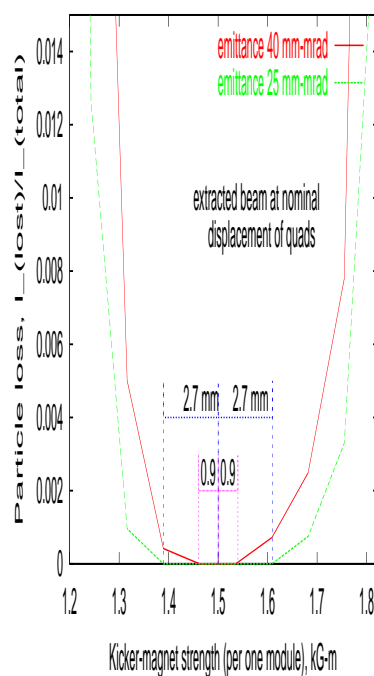
- Now kickers also run at nominal field





Extraction Channel Aperture Clearance (~ Same Scale Comparison)

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Gain > x10 in aperture clearance for 40 π beam



New Kicker and Lambertson Parameters

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Lambertson magnets							
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LAM60A	MI-60	2.8	3	34.6	12.357		4.2887
LAM60B,C	MI-60	2.8	3	34.6	12.357		10.72175

Kicker and Lambertson magnet parameters (three kicker modules)



Preliminary Cost Estimate

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Kicker					
Class	Item	Base \$	Added \$	Burdened	Comments
kicker	Kicker magnet deliveries	\$305,300	-\$27,800	-\$32,248	Now std. design
kicker	Kicker design (phase 2)	\$35,500	\$0	\$0	Now std. design
kicker	Kicker construction oversight	\$48,000	\$0	\$0	Now std. design
Kicker PS	Kicker PS eng. & design		\$31,571	\$41,200	3 mo. EE/ME
Kicker PS	M&S	\$300,000	\$30,000	\$34,800	10% more per C. Jensen
Total			\$33,771	\$43,752	
Lambertson					
Class	Item	Base \$	Added \$	Burdened	Comments
PS	500 KW PS (cables, controls etc.)		\$16,320	\$19,558	
PS	PS Regulation		\$20,000	\$24,650	
Total			\$36,320	\$44,208	
Total for Extraction			\$70,091	\$87,959	



Implementation Options

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- Modest differential cost to implement
 - « Re-baseline cost included four short kickers (three plus unique device spare - **could not purchase long ceramic vacuum tubes**).
 - « Now are recovering three long ceramic tubes from old TeV units, plus one MI era purchase with damaged (now repaired) flanges.
 - « Initial power supply study looks good for achieving rise-time with some PS mod. (5 batches very good, 6 batches okay)
- Additional MI tunnel insertion space required ~ 2.5 m.
- **No good staging option.**
 - « All upstream NuMI magnet alignment is impacted.
- Recommend proceeding with this (three kickers, 2 PS Lambertson) for the NuMI design.